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Predictability and Ensemble Forecast Skill Enhancement Based on the Probability Density Function Estimation

- Final Report -

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LONG-TERM GOAL

My long term goal is to make substantial contributions to enhancement of forecast skills concerning the oceans and atmosphere, by deepening our knowledge for the nature of predictability. I place my emphasis on transition mechanism between dynamical regimes of planetary flows and coherent structures from both Eulerian and Lagrangian points of view.

OBJECTIVES

I wish to develop theoretical frameworks for enhancement of predictability based on dynamical systems theory. To help enhance predictability of sudden and severe events, I wish to investigate transition mechanisms between dynamical regimes. I also wish to throw a bridge between Eulerian and Lagrangian viewpoints and explore impact of severe events on large-scale transport in planetary flows. Knowledge obtained by these predictability studies will lead to a design of comprehensive ensemble-forecast systems and data-adaptive observing systems.

APPROACH

To achieve my goals, I plan to develop new theories and improve already existing methodologies so that they can be combined systematically. I start from assessing and extending individual elements of the theoretical framework, and develop new theories to fill the gaps between them as necessary. My approach involves: identification and detection of the predictability elements, Eulerian and Lagrangian descriptions of the probability density function evolution, treatment of nonlinearity as well as additive and multiplicative stochasity in data assimilation systems. To improve forecast skills for severe and sudden events, I investigate role played by stochastic noises. Severe events can be viewed as rare extreme bursts and therefore may be related to stochastic noises whose probability distribution has heavy tail. I construct a new innovative methodology

for data assimilation systems subject to dynamical and observational noises with heavy-tail distributions. To explore impact of transient flow dynamics on large-scale transport, I combine geometrical approach of dynamical systems theory and spatio-temporal data analysis technique.

WORK COMPLETED

An innovative method for direct assimilation of Lagrangian data in meteorology and oceanography has been formulated based on the extended Kalman filter (EKF). The method has been applied to the point vortex systems. A classification of the Lagrangian trajectories has been made for practical applications of the direct Lagrangian data assimilation method to complex ocean circulation models.

In order to examine the predictability of the coherent structures in the stratified ocean, a layer-model for point vortex system has been investigated. Judicious observing system, including parameter-estimation capacity, has been designed for improved estimation of the flow dynamics in the unobserved sub-surface layers.

To study predictability concerning transition from oscillatory to singular behavior, an idealized, highly-nonlinear dynamical system has been developed. The model is based on interplay between restoring force and hysteria in inertia, which can be found in many physical systems. The bifurcation diagram has been investigated to enhance forecast skill for the sudden transition.

A hybrid transport theory (TIME: transport induced by mean-eddy interaction) has been formulated to estimate transport induced by the anomaly in the large-scale atmosphere and ocean flows. It has been extended to identify signature and analyze role of variability in application to a large-scale atmospheric flow.

A comprehensive study to analyze transport in the Monterey bay surface flow has been pursued. In contrast to conventional Eulerian analysis techniques, Lagrangian synoptic maps have been used to study the Lagrangian ocean surface properties.

To address extended-range predictability in terms of the multiple-regime paradigm and preferred transition paths between them, the three-level quasi-geostrophic (QG) model has been investigated. Preferred transitions paths are examined also for a stochastically forced Lorenz system, to help explain the striking feature of the QG model.

A new aspect for computing the stable and unstable manifolds of hyperbolic trajectories of two-dimensional aperiodically time-dependent velocity fields has been studied (Mancho et al. 2002). A skillful and practical numerical method has been presented.

RESULTS

The new Lagrangian data assimilation system augments the state variables with the Lagrangian tracer variables in addition to the prognostic variables of the dynamic model.

The EKF computes not only the state variables but also the error covariance matrix. Through the cross correlation, the new assimilation system updates the unobserved prognostic variables using the observed Lagrangian tracers. This is based on the same idea as the parameter estimation using the EKF. Figure 1 shows a successful application of the EKF to the surface layer observing system for estimation of the dynamics using the point-vortex model that is the lowest-order representation of the coherent structures in the large-scale ocean flows. Performance of the data assimilation system crucially depends on the judicious choice of the key parameters in the observing system, in particular observation frequency.

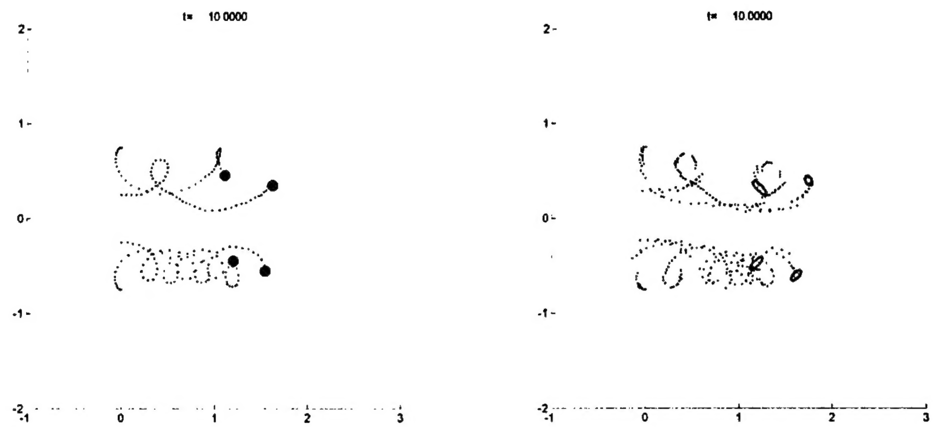

Figure 1. Surface layer observation system for subsurface layer estimation. [left: underlying truth by control run with surface (blue) and sub-surface (red) ocean dipole; right: successful data assimilation with parameter estimation]

By applying the mixture model clustering technique to leading-order empirical orthogonal functions of the 500hPa level streamfunction field obtained by the QG model simulation, the four robust regimes roughly corresponding to opposite phases of the Arctic Oscillation and the North Atlantic Oscillation are found (Figure 2). The preferred transition paths are found not to be aligned with the line segments between regime centroids in most cases. It might point to heteroclinic or homoclinic connections between unstable equilibria as demonstrated using the Lorenz equations.

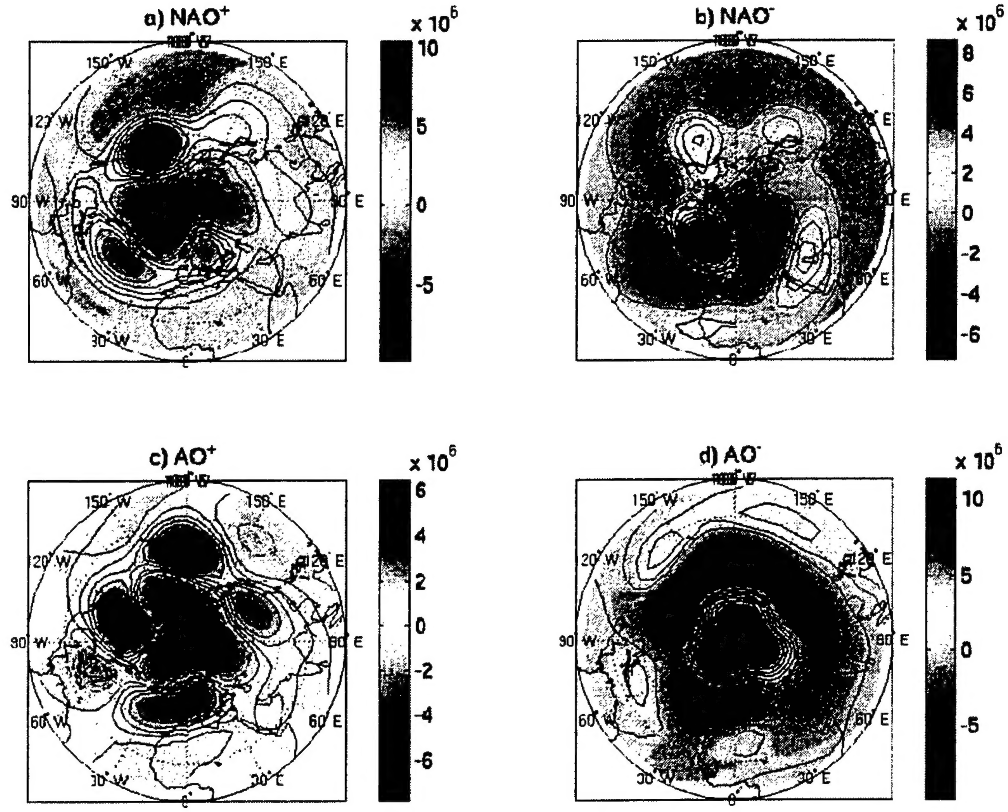

Figure 2. Streamfucntion filed of the four atmospheric weather regimes at 500hPa. [Positive (+) and negative (-) phases of North Atlantic Oscillation (NAO) and Arctic Oscillation (AO)]

The TIME theory is a hybrid of the Lagrangian and Eulerian methods. It estimates the leading-order Lagrangian transport using the Eulerian information extracted on the stationary boundary. Transport is presented as spatio-temporal integration of the instantaneous flux, which is induced by the temporally spontaneous but spatially nonlinear mean-eddy interaction. It offers two aspects of transport: accumulation and displacement geometry (left panel of Figure 2). Two complementary approaches are graphic (right panel of Figure 2) and analytic. Analytic approach suggests that the non-dimensional scale ratio defined by the characteristic length-scale of the flux variability in the unit of flight time and the characteristic time-scale of the anomaly in the general circulation.

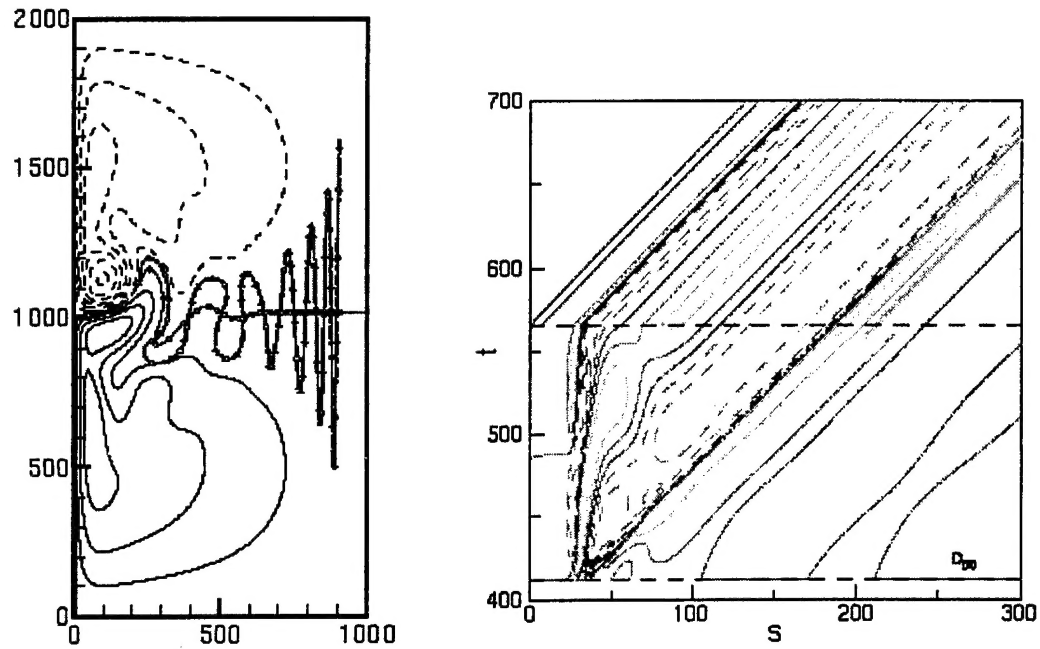

Figure 3. Inter-gyre transport in the wind-driven mid-latitude ocean due to the Rossby-wave mode variability [left: leading-order displacement geometry; right: transport process during one cycle of Rossby-wave oscillation]

IMPACT/APPLICATION

The new data assimilation methodology currently being developed in this work can fill the gap between data assimilation and dynamical systems approach to Lagrangian transport theory, which has been one of the focuses in the ONR predictability DRI program. The methodology is general and can be applied to numerous observations that have not been assimilated using the conventional assimilation methods.

Extended-range weather prediction depends in a crucial way on skill at forecasting the duration of a regime event or other persistent anomaly, as well as the subsequent onset of another persistent anomaly after the break of the current one. The result obtained may suggest that a similar analysis of numerical weather prediction models could help forecast well in advance regime breaks and subsequent onsets. To do so would require an efficiently designed observational system that is able to track spatial signatures of regime transitions.

Extending TIME theory offers a variety of new directions for large-scale planetary flows, including analysis of transport processes and mechanism, impact of specific events in the flow dynamics, as well as role played by variability.

RELATED PROJECTS

1– NSF CMG Heavy Tailed Distributions in Geophysical flow: Physical Mechanisms and Data Assimilation, in collaboration with Richard McLaughlin, Roberto Camassa and Christopher K.R.T. Jones (UNC-CH) and Didier Sornette (UCLA).

2– ONR Development of a Data Assimilation System (DAS) for the Regional Ocean Modeling System (ROMS) Towards an Operational Forecasting off the U.S. West, in collaboration with Yi Chao and Zhijin Li (JPL) and James C. McWilliams (UCLA).

3– Los Alamos National Laboratory project on data assimilation studies for shock wave physics in collaboration with Jim Kao (Los Alamos National Laboratory).

PUBLICATIONS

Chang, KI , M. Ghil, K. Ide and C.C. Lai, 2001. Transition to aperiodic variability in a wind-driven double-gyre circulation model, *J. Phys. Oceanogr.*, **31**, 1260-1286..

Sornette, D., and K. Ide, 2001. The Kalman-Levy filtering, *Physica D*, **151**, 142-174.

Ide, K and D. Sornette, 2002. Oscillatory finite-time singularities in finance, population and rapture, *Physica A*, **307**, 63-106.

Ide, K. and S. Wiggins, 2003. A new approach to transport induced by mean-eddy interaction for ocean circulations. *J. Phy. Oceanogr.*, submitted.

Ide, K., L. Kuznetsov and C.K.R.T. Jones, 2002. Lagrangian data assimilation for point-vortex systems. *J. Turb.*, **3**, 053.

Ide, K., D. Small and S. Wiggins, 2002. Distinguished hyperbolic trajectories in time dependent fluid flows: Analytical and computational approach for velocity field defined as data sets, *Nonlin. Proc. Geophys.*, **9**, 237-263.

Kuznetsov, L., K. Ide and C.K.R.T. Jones 2003. A method for assimilation of Lagrangian data. *Mon. Wea. Rev.*, accepted.

Mancho, A.M., D. Small, S. Wiggins and K. Ide, 2003. Computation of stable and unstable manifolds of hyperbolic trajectories in two-dimensional, aperiodically Time-dependent vector fields. *Physica D*, **182**, 188-222.

Simonnet, E., M. Ghil, K. Ide, R. Temam, S. Wang, 2003. Low-frequency variability in shallow-water models of the wind-driven ocean circulation. Part I: Steady-state solutions, *J. Phys. Oceanogr.*, **33**, 712-728..

Simonnet, E., M. Ghil, K. Ide, R. Temam, S. Wang, 2003. Low-frequency variability in shallow-water models of the wind-driven ocean circulation. Part II: Time-dependent solutions, *J. Phys. Oceanogr.*, **33**, 720-752.

Sornette, D., and K. Ide, 2003. Theory of self-similar oscillatory finite-time singularities in finance, population and rapture, *Int. J. Mod. Phys. C*, accepted.